EXPERIMENTS

ON THE

STRENGTH OF IRON RAILS

AT DIFFERENT TEMPERATURES.

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BEING THE APPENDIX TO HIS TRANSLATION OF A SWEDISH WORK
ON THE ELASTICITY, EXTENSIBILITY, AND TENSILE STRENGTH
OF IRON AND STEEL, BY KNUT STYFFE.

WITH A LITHOGRAPHIC PLATE.

LONDON:
PRINTED FOR PRIVATE CIRCULATION.
1869.

IRON AND STEEL.

APPENDIX

BY THE TRANSLATOR.

luction. — 2. Experiments on Iron exposed to sudden shocks at different ›eratures, the elasticity of the supports remaining constant or nearly so. Results of the experiments. — 4. Conclusions. — 5. Probable cause of results. — 6. Steel *versus* Iron.

1. *Introduction.*

ɔGH the extensive series of experiments conducted by the ·h Government Committee (consisting of Messrs. Ekman, and Grill), and described by the author in the previous had for their *special* object, to determine the value of ·h raw material for the manufacture of railway plant,— ɜ rails, axles, wheels, tyres, springs, &c.,—yet considering ;uracy with which these experiments were performed, their ıce to materials obtained from other countries, and the ɔf the conclusions to which they led, the translator has ıduced to regard them as worthy of attention not only by y engineers in general, but also by manufacturers of iron ɜel.

:he present time, when "Steel *versus* Iron" is the great ering question of the day, it becomes of special import- o collect all information tending to throw light upon the t, when founded upon experience, and free from partiality. ısidering whether steel should be substituted for iron, ı objections have long been brought forward, especially se countries which suffer from a severe climate, such, for ce, as the Scandinavian Peninsula, Russia, Canada, and rthern part of America.[1] On this point the author has, by

[1] general objection to the use of steel as a substitute for iron, is the want rmity in the manufacture. If steel could be depended upon in regard to ı, elasticity, &c., it would shortly take the place of iron at a considerably d price.—W. FAIRBAIRN.

his elaborate experiments, arrived at certain remarkable results which run directly counter to the general belief—results which show indeed that iron and steel are, if anything, actually stronger when exposed to severe cold than at ordinary temperatures. This was found to be the case in several experiments where iron and steel were tested as to extensibility, strength, and resistance to flexure. The author cannot, however, deny the fact that iron as well as steel when employed as railway material, and consequently exposed to sudden concussions, breaks more frequently during extreme cold than at ordinary temperatures; but he explains this fact by referring to the diminished elasticity of the supports on which the metal rests.[2] The author also admits that it is just when exposed to the most intense cold that fracture most commonly occurs; but this too he refers to the same cause, and concludes from his experiments on the elasticity of a wet wooden sleeper, that on a reduction of temperature from 35° to 2° F. the elasticity of the ground would be diminished by twelve per cent. (see page 113). From these experiments the author considers that the only means to prevent accidents on railways exposed to a severe climate is either to lessen the speed during winter or to give the rolling stock more elasticity by employment of india-rubber springs or otherwise.

In the winter of 1865, which was the first during which express trains were run between Stockholm and Gothenburg, an accident occurred which threatened to cast a mantle of mourning over the whole of Sweden. One morning in January,

[2] It does not appear that rigid supports, such as frozen ground, constitute the sole cause of the deterioration of iron and steel at a low temperature. It would operate to a small extent, but not sufficiently to account for the limited power of resistance as shown in the Table (p. 162 *et seq.*) at low temperatures. There is doubtless a molecular change in the material between the extremes of high and low temperatures, but even these are not considerable, as may be seen by my own experiments. It will be observed that these experiments commenced at a temperature of 30° below the freezing point of Fahr. up to 212° and 435° consecutively, and also to a red heat perceptible in daylight. Throughout all these changes, the *tensile* strength of plates and bar-iron was not seriously injured, and gave widely different results from those obtained in your case by *impact*. From this it would appear, that the *tenacity* of iron bars and plates is not seriously injured at a temperature as high as 435°, which is the maximum tensile strength, nor do they appear to suffer to any great extent when the temperature is reduced to 30° Fahr. At this temperature the *elasticity* is however considerably impaired, and much greater risk is incurred if subjected to vibratory action or a series of *impacts*. See paper 'On the Tensile Strength of Wrought Iron at various Temperatures,' published in the 'Transactions of the British Association for the Advancement of Science,' for 1856, p. 405.—W. FAIRBAIRN.

when the thermometer stood at − 20° F., His Majesty King Charles XV. left Stockholm by the ordinary express train. After proceeding for some hours at the speed of about 35 miles an hour, the tyre of one of the wheels under the royal carriage broke in three pieces, and the carriage having left the rails was dragged along the ballast for a considerable distance. Providentially no one was injured. Two days afterwards at a similar temperature another accident occurred also through a broken tyre, but fortunately was attended by no serious result beyond the shock given to a postmaster, who was in the mail-van, which rolled down a steep embankment. The occurrence of a third and similar accident, also during this severe weather, induced the railway authorities to decide on slackening the speed during the winter months to about 25 miles per hour; and since then no accident of that kind has occurred. The tyres which broke in these cases were of iron, made in England, and were fastened with bolts to ordinary iron wheels. Wooden disc-wheels have since been adopted with solid tyres, or without weld; and at the same time india-rubber springs have been introduced between the frame and the body of the carriages: these improvements have considerably increased the comfort of the passengers, and have prevented the occurrence of further accidents. It is remarkable that the three above-mentioned accidents should all have happened on the very days when the cold was severest, viz. − 20° F., but that none occurred during a frost in which the thermometer did not fall below 5° F.—a temperature by no means rare during several consecutive weeks in a Swedish winter.

In order to investigate the cause why iron in cases such as those just cited, is disposed to break more readily when subjected to blows during extreme cold than at ordinary temperatures, and in order to determine how far this is really due to diminished elasticity of the supports, and how far to increased brittleness in the metal itself, the translator proposed to the Royal Administration of Government Railways the execution of some experiments on a large scale and in a simple but practical manner. As the results of these investigations have already been given (note to page 114), the translator will now record the full details of these experiments, which tend to contradict some of the author's conclusions, as mentioned above.

2. *Experiments on Iron exposed to sudden Shocks at different Temperatures, the Elasticity of the Supports remaining constant or nearly so.*

Having been charged by the Royal Administration aforesaid with the execution of these experiments, the translator submitted his proposed *modus operandi* to the author. The greatest difficulty was to find supports which would not be affected by differences of temperature. It was assumed, however, that the elasticity of granite would not vary within the range of temperature between a hot summer and a cold winter day ; or at least not to an extent sufficient to vitiate the results of the experiments. Accordingly the translator conducted his investigations in the following manner :—A granite rock near Stockholm was levelled *in situ*, and upon this plane surface two cubic blocks of granite, each containing about ten cubic feet, were placed four feet apart, to serve as supports. A ball, weighing 9 cwt., was so adjusted that it could be raised to a height of 15 feet, and then allowed to fall on the rail, midway between the supports.[3] The bars tested were iron rails from the Aberdare Works in South Wales, and from Le Creusot in France—all bars being of exactly the same section, and made under the superintendence of the translator. Each rail was of Vignole's section, weighing 66 lbs. per yard, and measuring $4\frac{3}{4}$ inches high and 4 inches broad at the base. Two rails made in Belgium at the works of Messrs. Dorlodot were also tested, but these were of a lighter construction, weighing only about 50 lbs. per yard. All the rails were tested by the ball falling from a height of 5 feet for the first blow, with an increase of 1 foot for each succeeding blow until fracture occurred; the deflection being measured after each impact. A small piece of wrought iron was placed on the top of each rail-head so as to concentrate the effect of the blow, within a width of $1\frac{1}{2}$ inch. Each rail was first broken in the middle, and both halves (each 10·5 feet in length) were marked with the same number. Comparative experiments were then instituted with these halves, one being tested during the most severe cold of winter, and the other on a hot summer day, the average temperature during the former

[3] I may mention that all rigid supports are objectionable for the supports of railway bars, and that a compressible and elastic substance, such as wood bedded on earth is infinitely superior to stone-blocks, as the timber and porous earth act as a cushion to the rolling load. Many hundreds of miles laid with stone blocks had to be replaced with wood-sleepers at the commencement of railways.—W. Fairbairn.

experiment being 10° F., and during the latter 84° F. Unfortunately the winter was so far advanced when these experiments were commenced that the temperature never fell below 10° F.[4] Some of these rails were also tested in a similar manner at a temperature of 35° F.

The first part of the investigation was conducted under the personal superintendence of the translator, assisted by a foreman in the Government Railway Service. The latter part of the investigation (or the series of summer experiments) was, however, conducted by this foreman, in the absence of the translator, who was occupied in England during the entire summer on Government business. He has, however, every reason to believe that the experiments made in his absence are worthy of reliance. The Table on p. 162 *et seq.* gives the full details of these experiments, showing the length and quality of each rail, the number of blows delivered, the height of the fall of the ball, the deflection produced by each blow until fracture occurred, and the temperature at which the experiments were severally made. On examining this table, the first result which strikes the observer is the great variation in strength exhibited by different rails when broken in the middle. For example, Rail No. 4 broke at the first blow by a 5-feet fall, whilst another rail from the same works, No. 5, resisted five blows, each with an increasing height of one foot in the falling ball. Such a difference will, however, be easily understood by those practically acquainted with the manufacture of rails, when they remember how often the quality of the iron varies even in the same works, and how much it is influenced by the length of time the pile is kept in the furnace, and its liability to be over-heated if left there too long; all these causes having a tendency to make the rails differ widely in strength. It may nevertheless be fairly assumed that one-half of a rail will not differ to any great extent from the other half of the *same* rail; and it is on this assumption that the value of these experiments is based. To those, however, who urge that there may be a difference even in the same rail, it may be said that the great number of bars tested (namely, seven from Aberdare, five from Creusot, and two from Dorlodot's) would still give an average result sufficient to lead to

[4] In Sweden and Norway, and all northern countries where the winters are severe, double thickness in the wood-sleepers would offer increased security to the rails, and remove the jar or vibrating motion from the rails and the rolling load. —W. FAIRBAIRN.

definite conclusions. The total height expressed in feet from which the ball fell before each rail broke may therefore serve as a comparative numerical expression for the resistance and strength exhibited in these experiments.

3. *Results of the Experiments.*

From the details given in the Table on p. 162 *et seq.*, we deduce the totals, shown in the following tabular form :—

TOTAL HEIGHT of the FALL of the BALL, required to break each Rail at different Temperatures.

Works where the Rails were made.	No. of Rails tried.	Rails 21 Feet long. Temperature, F.			Rails 10·5 Feet long. Temperature. F.		
		84°	35°	10°	84°	35°	10°
		Total Height of Fall in Feet.					
Aberdare (Wales)	1	..	11	..	45	26	..
,, ,, ...	2	..	11	..	56	26	..
,, ,, ...	3	..	18	..	35·5	11	..
,, ,, ...	4	..	5	..	45·3	5	..
,, ,, ...	5	..	45	..	56	..	18
,, ,, ...	6	..	..	11	56	..	5
,, ,, ...	7	..	..	5	35	..	5
Le Creusot (France) ..	1	..	26	..	45	..	26
,, ,, ...	2	..	18	..	35	..	11
,, ,, ...	3	..	11	..	35	..	18
,, ,, ...	4	..	35	..	45	..	11
,, ,, ...	5	..	26	..	35	..	5
Dorlodot's (Belgium) ..	1	..	..	4	22	..	9
,, ,,	2	..	..	4	30	..	4
Average of—							
7 English Rails ..	..	..	18	8	49·6	17	9·3
5 French do.	..	..	23·2	..	39	..	14·2
2 Belgian do.	..	..	..	4	26	..	6·5
Average of— 3 English Rails .. 5 French do. .. .. 2 Belgian do.	..	..	..	..	39	..	11

Thus the average results obtained from ten rails show that one end of a bar tested at 84° F. resisted a blow from the *height of* 39 *feet*, whilst the other end, tested at 10° F., only sustained a blow from the *height of* 11 *feet.*

This table gives the number of each rail, the total fall in feet by which the rail was first broken in two, and the resistance of each half thus obtained when tested at different temperatures. The total of the results for each kind of rail divided by the number examined gives the average for each make, as shown in the lower part of the table. The results thus obtained show that when the elasticity of the supports remained constant, the same rails tested by sudden shocks at temperatures of 84° F. and 10° F. exhibited differences in strength which may be expressed by the numbers 39 and 11 respectively; these figures representing the total height in feet of the falling ball which the two halves of each rail resisted when tested, the one at 84° F., the other at 10° F.

4. *Conclusions.*

From these experiments the translator is led to draw the following conclusions:—

1. That for such iron as is usually employed for rails in the three principal rail-making countries (Wales, France, and Belgium), the breaking strain, as tested by sudden blows or shocks, is considerably influenced by cold; such iron exhibiting at 10° F. only from one-third to one-fourth of the strength which it possesses at 84° F.
2. That the ductility and flexibility of such iron is also much affected by cold; rails broken at 10° F., showing on an average a permanent deflection of less than one inch, whilst the other halves of the same rails, broken at 84° F., showed a set of more than four inches before fracture.
3. That at summer-heat the strength of the Aberdare rails was 20% greater than that of the Creusot rails; but that in winter the latter were 30% stronger than the former.

5. *Probable Cause of the Results obtained by Experiments on Concussion at different Temperatures.*

We have long been familiar with the term "cold-short" as applied to iron, and have supposed that the presence of phosphorus induces this property by rendering the metal extremely

brittle when exposed to cold.[5] The experiments just described were certainly made with cold-short iron (unfortunately the amount of phosphorus was not determined, but rails from Cwm Avon were found to contain 0·24% of phosphorus, as shown on p. 132), and it is therefore not improbable that the phosphorus generally present in iron rails may have given rise to the apparent contradiction between the translator's results and those deduced from previous experiments made by the author. It should, however, be remembered that the translator's results were obtained by sudden shocks, whilst the author's experiments were on gradual bending and stretching; so that the two results are not fairly comparable. It is only when the author applies *his* experiments to railway materials (which from their position are necessarily exposed to sudden shocks), and thence concludes that such materials are more subject to fracture in winter than in summer, ***solely through a difference of elasticity in the supports***, that the translator feels compelled to differ from him. Although the experiments on which the translator grounds this opposition were made with a somewhat rude arrangement, yet they clearly show that at any rate such iron as that generally used for rails is in its resistance to blows influenced to a very great extent by cold. Had the iron been free from phosphorus, or nearly so, it is highly probable that different results would have been obtained. It is also to be regretted that the effect of temperature on the strength of superior kinds of iron and *steel* was not determined at the time the experiments were made; no steel rails had, however, been then imported into Sweden.

6. *Steel* versus *Iron.*

It may be seen from the author's experiments, as well as from his conclusions, that for the most important articles steel is recommended in preference to iron; and for countries which, like Sweden, suffer from severity of climate, the author recommends a *mild steel*, not only for railway materials but also for ship-plates, bridges, girders, boilers, and indeed for nearly all the

[5] No doubt phosphorus and sulphur may account for the loss of strength indicated in these experiments, but is inconclusive unless the quantity is determined. —W. FAIRBAIRN.

principal articles of ordinary iron-manufacture. The author justly says that it is only in consequence of its high price that steel has hitherto been retarded in its advance as a substitute for iron; but now, through the invention of the Bessemer process and the great progress it has recently made, this obstacle is removed to a very great extent.

In these remarks the translator fully concurs, and he has therefore united, in Plate IX., the two Plates III. and IV.; and has drawn with black lines all the curves showing the tensile strength of Bessemer and cast steel, leaving the other curves in dotted lines.

From this table it may be easily seen that the Bessemer material is capable of standing nearly the same test of tensile strength as any other steel—whether made by puddling, by charcoal-refining, or by the cast-steel process—provided that the raw material is equally free from phosphorus, and that the product obtained has the same degree of hardness, or in other words contains the same proportion of carbon. The curves run very nearly parallel from the hardest steel with 1·2% of carbon to the softest iron with 0·2%, although the product might have been made by different processes, in different countries, and from different raw materials. In the properties of iron or steel made by dissimilar methods there may be slight differences as to soundness and homogeneity, which are not shown by these experiments. In this respect, however, Bessemer steel and cast-steel are certainly preferable to iron or puddled material, since this is seldom free from welding-joints.

On this point the translator would only remark that all the *Bessemer steel*, the results of which are represented in curves on the plan, was made from pure Swedish charcoal pig-iron, which contained but a very small proportion of such impurities as phosphorus and sulphur, and only about 1% of silicon. It has lately been observed in several works in England that the action of silicon is similar to that of carbon in giving hardness to steel. The same thing has also been found in practice in Austria, for on changing the raw material from charcoal to coke pig-iron the steel acquired hardness and brittleness (see Professor Tunner's letter to Dr. Percy in a paper "On the Manufacture and Wear of Rails."—*Proc. Inst. Civ. Engineers*, 1868).

All the pig-iron used in England and in Westphalia for the Bessemer process is made by coke from Hæmatite ore, and contains on an average 2·5% of silicon. Although the amount of

impurities in the shape of phosphorus and sulphur is not greatly in excess of that present in charcoal pig-iron, yet the steel produced from the coke iron is not equal in quality to that made from charcoal iron. As long therefore as any abundance of charcoal pig-iron may be obtained in the market at an advanced price of not more than 20*s.* per ton—whether from Canada, Nova Scotia, Sweden, or Norway—it would be bad policy for manufacturers of steel by the Bessemer process to allow so slight a difference in the cost of the raw material to affect their considerations, especially when manufacturing superior articles—such as shafts, axles, tyres, girders, plates, &c. For rails, however, coke pig-iron is sufficiently good if properly converted in the Bessemer vessel. The choice of raw material is of more importance for the Bessemer process than for any other mode of manufacture, since the impurities are not carried off to the same extent by that process as they are, for example, by puddling. It may be of interest to mention that even with the Swedish charcoal pig-iron the best qualities yield a superior steel by the Bessemer, as well as by all other processes. The Dannemora iron, for example, has yielded a Bessemer steel, which has been tested in Sheffield for use in cutlery with the most satisfactory results, and found superior to the Bessemer steel made from ordinary brands of Swedish pig-iron.

The continued reduction in the price of Bessemer and cast-steel by improvements in their manufacture is certainly of the greatest benefit to the world. Indeed, there is every reason to believe that ere long we shall obtain Bessemer steel for the same price as iron, and thus avoid all want of homogeneity from welding-joints and other causes; the only difference being an addition of about 20*s.* per ton in the price of the pig-iron employed, for the fuel and labour expended in the Bessemer process have already been reduced to the same as, or even to less than, their cost by either the puddling or the finery process.

For the determination of the carbon, silicon, sulphur, phosphorus, and other constituents of steel, there are already many new methods in successful operation at the different steel works; nearly all of them now possessing a laboratory and a chemist of their own, which is but seldom the case at iron works. Still it behoves the consumer to pay much more regard to a thorough examination of the character of the steel which he receives, and not to be led away by mere lowness of price: for the loss resulting from a single accident due to inferior

metal may far exceed the amount saved in the difference of cost between good and bad material. Having himself no interest to advance in advocating the employment of either one or the other material, the translator is disposed to think that the author's experiments, performed as they were with the greatest accuracy, skill, and impartiality, and at the expense of a foreign Government, may not be without interest to the manufacturers, as well as to the consumers of iron and steel in this country. He therefore indulges the hope that his task of translating the work into the English language may not be altogether in vain. At the same time he solicits the indulgence of the public for the errors that he may unwittingly have committed, and begs in conclusion to tender his sincere thanks to Dr. Percy and Dr. Fairbairn for their valuable assistance.

TABLE TO THE APPENDIX.

EXPERIMENTS WITH RAILS, tested by a Falling Weight at different Temperatures, conducted by the Translator for the Swedish Government Administration, Stockholm. 1867.

	No. of blows.	Height of fall of the ball in feet.	Permanent deflection.	Broke.	Temperature. Deg. Fahr.
Aberdare rail No. 1. 21 ft. long ..	1	5	1		35
,, ,, ..	2	6	..	Broke	,,
One half of the same rail	1	5	1		,,
,, ,, ...	2	6	$1\frac{3}{4}$		,,
,, ,, ...	3	7	$2\frac{3}{4}$		,,
,, ,, ...	4	8	..	Broke	,,
The other half of the same rail	1	5	$\frac{7}{8}$		84
,, ,, ...	2	6	$1\frac{3}{4}$		,,
,, ,, ...	3	7	$2\frac{3}{4}$		,,
,, ,, ...	4	8	$4\frac{1}{4}$		,,
Became twisted and could not be tested	5	9	$5\frac{1}{2}$		,,
further	6	10	6	Broke	,,
Aberdare rail No. 2. 21 ft. long ..	1	5	$\frac{1}{2}$		35
,, ,, ..	2	6	..	Broke	,,
One half of the same rail	1	5	$\frac{3}{4}$		,,
,, ,, ...	2	6	$1\frac{3}{4}$		,,
,, ,, ...	3	7	$2\frac{3}{4}$		,,
,, ,, ...	4	8	..	Broke	,,
The other half of same rail	1	5	$\frac{7}{8}$		84
,, ,, ...	2	6	$1\frac{3}{4}$		,,
,, ,, ...	3	7	$2\frac{7}{8}$		,,
,, ,, ...	4	8	4		,,
,, ,, ...	5	9	$5\frac{1}{4}$		,,
,, ,, ...	6	10	$6\frac{3}{4}$		,,
,, ,, ...	7	11	..	Broke	,,
Aberdare rail No. 3. 21 ft. long ..	1	5	$\frac{1}{2}$		35
,, ,, ..	2	6	1		,,
,, ,, ..	3	7	..	Broke	,,
One half of same rail	1	5	$\frac{3}{4}$		,,
,, ,, ...	2	6	..	Broke	,,
The other half of same rail	1	5	$\frac{7}{8}$		84
,, ,, ...	2	6	$1\frac{7}{8}$		,,
,, ,, ...	3	7	3		,,
Became twisted and could not be	4	8	$4\frac{1}{8}$		,,
properly tested further	5	9	$4\frac{1}{2}$	Broke	,,

Table to the Appendix—*continued.*

	No. of blows.	Height of fall of the ball in feet.	Permanent deflection.	Broke.	Temperature. Deg. Fahr.
Aberdare rail No. 4. 21 ft. long ..	1	5	..	Broke	35
The one half of same rail	1	5	..	do.	,,
The other half of same rail	1	5	$\frac{3}{4}$		84
,, ,, ...	2	6	$1\frac{3}{4}$		,,
,, ,, ...	3	7	$2\frac{7}{8}$		,,
,, ,, ...	4	8	$3\frac{7}{8}$		,,
Became twisted and could not be tried	5	9	$4\frac{3}{4}$		,,
further	6	10	$6\frac{3}{4}$	Broke	,,
Aberdare rail No. 5. 21 ft.	1	5	$\frac{1}{2}$		35
,, ,, ...	2	6	1		,,
,, ,, ...	3	7	$1\frac{1}{4}$		,,
,, ,, ...	4	8	$2\frac{1}{2}$		,,
,, ,, ...	5	9	$3\frac{3}{8}$		,,
,, ,, ...	6	10	..	Broke	,,
One half of the same rail	1	5	$\frac{3}{4}$		10
,, ,, ...	2	6	$1\frac{3}{4}$		,,
,, ,, ...	3	7	..	Broke	,,
The other half of same rail	1	5	1		84
,, ,, ...	2	6	2		,,
,, ,, ...	3	7	3		,,
,, ,, ...	4	8	$4\frac{1}{2}$		,,
,, ,, ...	5	9	6		,,
,, ,, ...	6	10	$7\frac{1}{2}$		,,
,, ,, ...	7	11	..	Broke	,,
Aberdare rail No. 6. 21 ft.	1	5	$\frac{3}{4}$		10
,, ,, ...	2	6	..	Broke	,,
The one half of same rail	1	5	..	do.	,,
The other half of same rail	1	5	$\frac{3}{4}$		84
,, ,, ...	2	6	$1\frac{7}{8}$		,,
,, ,, ...	3	7	$2\frac{7}{8}$		,,
,, ,, ...	4	8	4		,,
,, ,, ...	5	9	$5\frac{1}{2}$		,,
,, ,, ...	6	10	$7\frac{1}{2}$		,,
,, ,, ...	7	11	..	Broke	,,
Aberdare rail No. 7. 21 ft.	1	5	..	Broke	10
The one half of same rail	1	5	..	do.	,,
The other half of same rail	1	5	1		84
,, ,, ...	2	6	$1\frac{7}{8}$		,,
,, ,, ...	3	7	3		,,
,, ,, ...	4	8	$4\frac{1}{2}$		,,
,, ,, ...	5	9	..	Broke	,,

REMARKS.—The rails were supported by two granite blocks, 4 feet apart, which rested on a planed granite-rock. The weight of the ball was 9 cwt., and the permanent deflection was measured between a distance of 4 feet.

Table to the Appendix—*continued*.

	No. of blows.	Height of fall of the ball in feet.	Permanent deflection.	Broke.	Temperature. Deg. Fahr.
Creusot rail No. 1. 21 ft.	1	5	$\frac{1}{2}$		35
,, ,, ...	2	6	1		,,
,, ,, ...	3	7	$1\frac{5}{8}$		,,
,, ,, ...	4	8	..	Broke	,,
The one half of same rail	1	5	$\frac{3}{4}$		10
,, ,, ...	2	6	$1\frac{7}{8}$		,,
,, ,, ...	3	7	$2\frac{1}{2}$		,,
,, ,, ...	4	8	..	Broke	,,
The other half of same rail	1	5	$\frac{3}{4}$		84
,, ,, ...	2	6	$1\frac{3}{4}$		,,
,, ,, ...	3	7	$2\frac{1}{2}$		,,
,, ,, ...	4	8	$3\frac{1}{2}$		,,
,, ,, ...	5	9	$4\frac{1}{2}$		,,
,, ,, ...	6	10	..	Broke	,,
Creusot rail No. 2. 21 ft.	1	5	$\frac{1}{2}$		35
,, ,, ...	2	6	1		,,
,, ,, ...	3	7	..	Broke	,,
One half of the same rail	1	5	$\frac{3}{4}$		10
,, ,, ...	2	6	..	Broke	,,
The other half of same rail	1	5	1		84
,, ,, ...	2	6	$1\frac{1}{2}$		,,
,, ,, ...	3	7	$2\frac{1}{2}$		,,
,, ,, ...	4	8	4		,,
,, ,, ...	5	9	..	Broke	,,
Creusot rail No. 3. 21 ft.	1	5	$\frac{1}{2}$		35
,, ,, ...	2	6	..	Broke	,,
One half of the same rail	1	5	$\frac{3}{4}$		10
,, ,, ...	2	6	$1\frac{3}{4}$		,,
,, ,, ...	3	7	..	Broke	,,
The other half of same rail	1	5	$\frac{3}{4}$		84
,, ,, ...	2	6	$1\frac{1}{2}$		,,
,, ,, ...	3	7	$2\frac{1}{2}$		,,
,, ,, ...	4	8	$3\frac{1}{2}$		,,
,, ,, ...	5	9	..	Broke	,,
Creusot rail No. 4. 21 ft.	1	5	$\frac{1}{2}$		35
,, ,, ...	2	6	1		,,
,, ,, ...	3	7	$1\frac{5}{8}$		,,
,, ,, ...	4	8	$2\frac{3}{4}$		,,
,, ,, ...	5	9	..	Broke	,,
One half of the same rail	1	5	$\frac{3}{4}$		10
,, ,, ...	2	6	..	Broke	,,
The other half of same rail	1	5	$\frac{3}{4}$		84
,, ,, ...	2	6	$1\frac{3}{4}$		,,
,, ,, ...	3	7	$2\frac{3}{4}$		,,
,, ,, ...	4	8	4		,,
,, ,, ...	5	9	$4\frac{7}{8}$		,,
,, ,, ...	6	10	..	Broke	,,